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Using squeeze-film effect to reduce surface friction in electrostatic actuators

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This paper presents a method of reducing load friction in two degrees-of-freedom (2-DOF) transparent electrostatic induction actuator by using vibration-induced squeeze film effect. An experimental set-up was built to prove the concept. An overall 70% reduction in required driving voltage was obtained when the squeeze film is present.

1 Introduction

Electrostatic film actuators are thin, lightweight and flexible actuators composed of fully transparent plastic films etched with fine-pitched electrodes. They have very wide areas of application such as particle transportation or flexible muscle actuation, but feature most prominently in haptcis and human-machine interfaces where their transparency allows them to be overlaid onto any traditional display surface or game board. This allows enhancing these interfaces with actuation, motion and feedback capabilities [1–4].

Despite their usefulness, a disadvantage of electrostatic actuators is the fact that they require a layer of very small glass beads between stator and slider films to act as both gap material and friction reducer. This reduces the feasibility of the actuators since the glass beads require periodic reapplication and also create a mess around the area in use.

The necessity for glass beads can be reduced or totally eliminated by inducing a squeeze film between the contact surfaces through controlled piezoelectric vibration. This vibration traps a very thin layer of air (or any other gas) between parallel plate surfaces thereby creating the squeeze film effect [5–12]. This thin air layer can successfully substitute the use of glass beads in electrostatic film actuators.

2 Study of glass plate vibration

The transparent electrostatic actuator consists of a layer of film with electrodes printed onto a large glass plate substrate. A large voltage is applied to the electrodes, whereby an electrostatic force is exerted upon a dielectric sheet placed on top. This controllable force enables the dielectric sheet to move across the surface. Small glass beads need to be spread onto the actuator surface in order to both provide an air gap and reduce friction between actuated sheet and actuator surface.

In order to eliminate the need for these beads, squeeze film effect is employed. The squeeze film effect is the effect whereby a very thin layer of gas gets trapped between relatively large, parallel plate surfaces if these are kept in relative motion versus one another. This effect is the result of an overpressure phenomenon present between the surfaces.

The design methodology closely follows the one presented in [13], with a significant difference in the size scope of the application. While Giraud et al. employ the effect for tactile friction modulation on a relatively small 4.3 inch LCD, the plate used as base for the electrostatic actuator measures 345 mm in length, its width is 250 mm with a thickness of 1.8 mm. A full modal, frequency and time analysis of the vibration of such a size plate is performed in order to size the required actuators to excite the correct mode of vibration, beyond human hearing range. One such mode obtained is at 21.7 kHz. The resulting vibration half-wavelength is 15 mm. This is shown in Fig. 1.

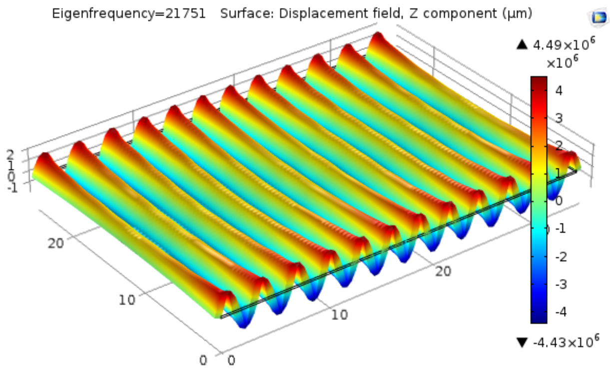

Fig. 1 Snapshot of time-domain vibration propagation analysis in the glass plate subjected to sinusoidal excitation at 21.7 kHz.

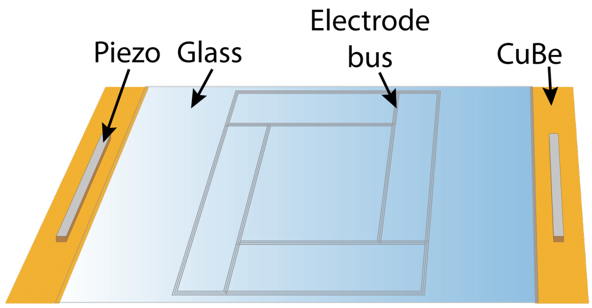

Fig. 2 Resonating glass-base electrostatic actuator system sketch.

3 System design

In order to excite the glass plate to vibrate at the obtained resonant frequency, two copper-berylium resonators with attached piezoelectric actuators were sized and glued to the glass plate through epoxy resin. The resonators measure 250 mm x 50 mm x 2 mm, where the long edge has to fit the glass plate while the width is determined by the desired resonance frequency. The initial design used six 11 mm x 50 mm x 1 mm piezos on each resonator, designed to operate in d31

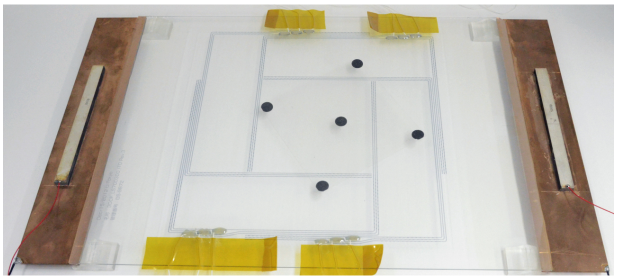

Fig. 3 Photo of the final system, with plastic actuated sheet shown on top of the actuator surface.

mode. Due to long delivery time of the desired piezos, these were substituted with two 120 mm x 10 mm x 5 mm actuators which were readily available. The difference in size with respect to the original design resulted in a resonance frequency shift of the entire system into the audible range. The sketch of the designed system is shown in Fig. 2, while the actual final system is presented in Fig. 3.

4 Results and conclusion

In order to generate a sizable electrostatic force that can overcome stick-slip of the chosen dielectric sheet (visible on top of the actuator surface in Fig. 3) without using any glass beads or squeeze film, a voltage of 500 V needs to be applied to the electrodes. With the vibration system turned on, this minimum voltage is reduced to only 150 V. That equates to a 70% reduction in electrostatic voltage requirements to overcome stick-slip, which can be attributed a corresponding reduction in friction between the actuated sheet and actuator surface. Moreover, using the originally-designed piezoelectric actuators would push the system resonance frequency to above hearing range, making it more suitable for human interaction.

All in all, squeeze film effect is successfully employed in order to eliminate the need for glass beads in transparent rigid-plate surface electrostatic actuators, but the actual operation of the actuator seems to depend on other influencing factors, such as humidity. Therefore, the overall system will be the subject of further analysis and improvement.

5 Acknowledgement

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